

UNRAVELING THE MYSTERY OF GENERAL AVIATION CONTROLLED FLIGHT INTO TERRAIN ACCIDENTS USING HFACS

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ABSTRACT

As part of the Federal Aviation Administration's *Safer Skies* agenda, a Joint Safety Analysis Team (JSAT) was formed to review general aviation (GA) controlled flight into terrain (CFIT) accidents and recommend strategies to prevent their occurrence and/or mitigate their consequences. The JSAT reviewed 195 CFIT accidents occurring over a 2-year period between 1993 and 1994 and developed 55 interventions to address the causes. While a root cause analysis technique was employed during the review, the findings might have benefited from a more traditional human error analysis. In this study, the GA CFIT accidents reviewed by the JSAT were reexamined using the Human Factors Analysis and Classification System (HFACS) to determine if additional support for the identified interventions could be obtained and/or additional strategies identified. The causal factors associated with 164 fixed-wing GA CFIT accidents were classified using HFACS by 3 independent

ratars. Roughly 50% of the accidents examined were associated with decision errors, 45% with skill-based errors, 30% with violations, and 20% with perceptual errors. More important however, were the differences observed between fatal and non-fatal CFIT accidents. Significantly, more fatal than non-fatal accidents were associated with violations. In contrast, decision errors were more often associated with non-fatal CFIT accidents. When the NTSB considered weather a factor, significantly more CFIT accidents were associated with violations and decision errors. These findings support many of the interventions identified by the JSAT, including decision-making aides and recurrent pilot training. The information provided by the HFACS analysis will assist in the development, refinement, and more importantly, tracking the effectiveness of selected intervention strategies.

INTRODUCTION

Aviation continues to be one of the safest forms of transportation, and with the help of modern technology, is enjoying its safest years ever. Still, accidents do occur, leaving accident investigators with the unenviable task of identifying the causes, so that similar accidents can be prevented. Perhaps the most compelling of all aviation accidents, are those where a perfectly good aircraft is inexplicably flown into the ground. These so-called controlled flight into terrain (CFIT) accidents continue to be a major safety concern within both civilian and military aviation.

While definitions of CFIT vary within the literature, most agree that CFIT occurs when an airworthy aircraft, under the control of a pilot, is flown into terrain (water or obstacles) with

inadequate awareness on the part of the pilot of the impending disaster (FAA, 2000). Using this definition, the U.S. Navy/Marine Corps alone lost an average of ten aircraft per year to CFIT between 1983 and 1995 (Shappell & Wiegmann, 1995, 1997b). Likewise, between 1990 and 1999, 25% of all fatal airline accidents and 32% of worldwide airline fatalities (2,111 lives lost) were the result of CFIT (Boeing, 2000). In fact, since 1990, no other type of airline accident has taken more lives.

While CFIT accidents in the military and commercial aviation certainly warrant the attention they receive, often forgotten is the even greater number of CFIT among general aviation (GA). To put it into perspective, while the U.S. Navy/Marine Corps lose on average between 20-30 aircraft annually for a variety of reasons, there were over 3,900 fatal GA accidents between 1990 and 1999; an average of nearly 400 fatal accidents per year (NTSB, 2001). Even if only

10% of those GA accidents were CFIT (well below the averages reported in commercial or military aviation), this would account for a minimum of 40 fatal accidents per year – not including those in which a fatality did not occur.

CFIT Joint Safety Analysis Team (JSAT)

On April 14, 1998, the Administrator of the Federal Aviation Administration (FAA) outlined the Administration's safety agenda for general aviation, commercial aviation, and cabin safety. Referred to as *Safer Skies*, the goal for general aviation was to significantly reduce fatal accidents over a 10-year period from 1996 to 2007. To accomplish that goal six focus areas were targeted for general aviation of which CFIT was one. In response, the CFIT JSAT was formed in the fall of 1998 and chartered to make recommendations on intervention strategies aimed at reducing the number of GA CFIT accidents.

Using CFIT accidents identified by the Volpe Center CFIT Study (Volpe, 1997), the CFIT JSAT proceeded to examine 195 fatal and non-fatal general aviation operations occurring between 1993 and 1994. Using a root cause analysis approach, the JSAT developed 55 interventions to address the causes associated with CFIT accidents. The efforts of the CFIT JSAT are commendable and represent the views of experts from industry, government and academia. However, the findings might benefit from a traditional human error analysis such as the Human Factors Analysis and Classification System (HFACS) which has been shown to be useful in other aviation arenas (Shappell & Wiegmann, 2000a; 2001).

HFACS

It is generally accepted that aviation mishaps, like most accidents, do not happen in isolation. Rather, they are the result of a chain of events often culminating in the unsafe acts of aircrew. From Heinrich's (Heinrich, Peterson, & Roos, 1931) axioms of industrial safety, to Bird's (1974) "Domino theory" and Reason's (1990) "Swiss cheese" model of human error, a sequential theory of accident causation has been embraced by many in the field. Particularly useful in this regard has been Reason's (1990)

description of active and latent failures within the context of his "Swiss cheese" model of human error.

In general, Reason described four levels of human failure, each one influencing the next: 1) Organizational influences, 2) Unsafe supervision, 3) Preconditions for unsafe acts, and 4) The unsafe acts of operators. Still, while Reason's seminal work revolutionized the way aviation and other accident investigators view the human causes of accidents, it did not provide the level of detail necessary to apply it in the real world. Consequently, HFACS was developed to fill that need (Shappell & Wiegmann, 2000a; 2001).

Drawing upon Reason's (1990) original work, HFACS describes 17 causal categories within four levels of human failure (Figure 1). Not surprising, prior investigations (Shappell & Wiegmann, 2000b) have shown that causal factors associated with general aviation accidents typically only populate the bottom two tiers of HFACS. Consequently, only the bottom two tiers will be briefly described here. A complete description of all four tiers can be found elsewhere (Shappell & Wiegmann, 1997a; 2000a; 2001).

Unsafe Acts of Operators

The unsafe acts of operators (aircrew) can be loosely classified into one of two categories: errors and violations. While both are common within most settings, they differ markedly when the rules and regulations of an organization are considered. That is, errors can be described as those "legal" activities that fail to achieve their intended outcome, while violations are commonly defined as behavior that represents the willful disregard for the rules and regulations. It is within these two overarching categories that HFACS describes three types of errors (decision, skill-based, and perceptual) and two types of violations (routine and exceptional).

Errors

One of the more common error forms, decision errors, represent conscious, goal-intended behavior that proceeds as designed, yet the plan proves inadequate or inappropriate for the situation. Often referred to as "honest mistakes", these unsafe acts typically manifest as

poorly executed procedures, improper choices, or simply the misinterpretation or misuse of relevant information.

In contrast to decision errors, the second error form, skill-based errors, occur with little or no conscious thought. Just as little thought goes into turning one's steering wheel or shifting gears in an automobile, basic flight skills such as stick and rudder movements and visual scanning often occur without conscious thought. The difficulty with these seemingly automatic behaviors is that they are particularly susceptible to attention and/or memory failures. As a result, skill-based errors such as the breakdown in visual scan patterns, inadvertent activation/deactivation of switches, forgotten intentions, and omitted items in checklists often appear. Even the manner (or

skill) with which one flies an aircraft (aggressive, tentative, or controlled) can affect safety.

While, decision and skill-based errors have dominated most accident databases and have therefore been included in most error frameworks, perceptual errors have received comparatively less attention. No less important, perceptual errors occur when sensory input is degraded or 'unusual' as is often the case when flying at night, in the weather, or in other visually impoverished environments. Faced with acting on imperfect information, aircrew run the risk of misjudging distances, altitude, and decent rates, as well as a responding incorrectly to a variety of visual/vestibular illusions.

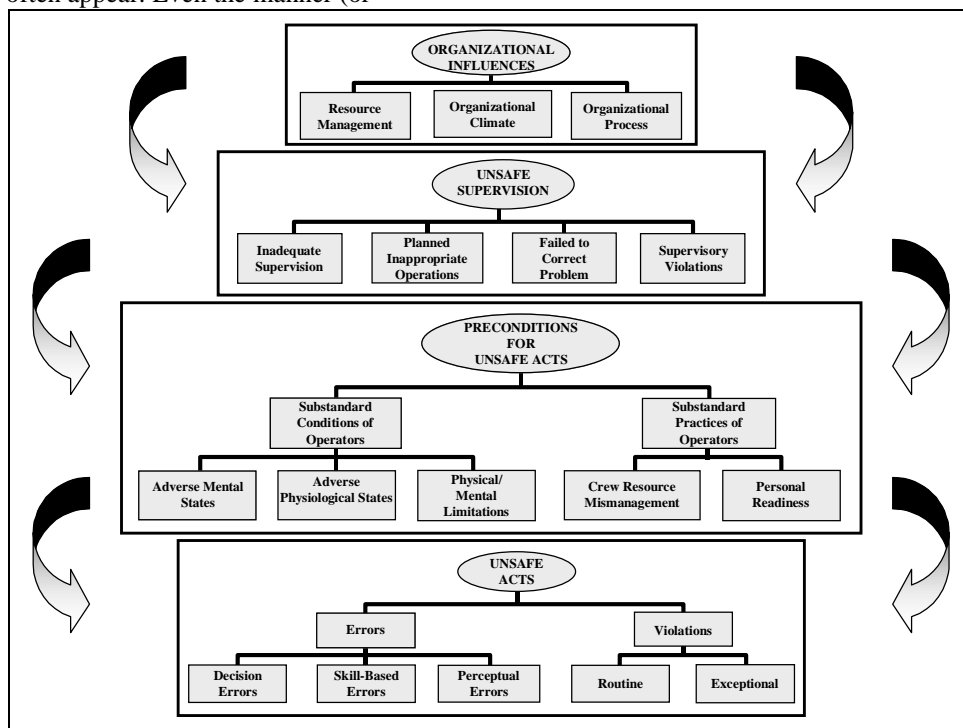


Figure 1. The Human Factors Analysis and Classification System (HFACS)

Violations

Although there are many ways to distinguish between types of violations, two distinct forms have been identified based on their etiology. The first, routine violations tend to be habitual by nature and are often enabled by a system of supervision and management that tolerates such departures from the rules (Reason, 1990). Often referred to as bending the rules, the classic example is that of the individual who drives his/her automobile consistently 5-10 mph

faster than allowed by law. While clearly against the law, the behavior is, in effect, sanctioned by local authorities (police) who often will not enforce the law until speeds in excess of 10 mph over the posted limit are obtained.

Exceptional violations, on the other hand, are isolated departures from authority, neither typical of the individual nor condoned by management. For example, while driving 65 in a 55 mph zone might be condoned by authorities, driving 105 mph in a 55

mph zone certainly would not. It is important to note, that while most exceptional violations are appalling, they are not considered 'exceptional' because of their extreme nature. Rather, they are regarded as exceptional because they are neither typical of the individual nor condoned by authority.

Preconditions for Unsafe Acts

Simply focusing on unsafe acts, however, is like focusing on a patient's symptoms without understanding the underlying disease state that caused it. As such, investigators must dig deeper into the preconditions for unsafe acts. Within HFACS, two major subdivisions are described: Substandard conditions of operators and the substandard practices they commit.

Substandard Conditions of the Operator.

Being prepared mentally is critical in nearly every endeavor, perhaps more so in aviation. With this in mind, the first of three categories, adverse mental states, was created to account for those mental conditions that adversely affect performance. Principal among these are the loss of situational awareness, mental fatigue, and pernicious attitudes such as overconfidence and complacency that negatively impact decisions and contribute to unsafe acts.

Equally important however, are those adverse physiological states that preclude the safe conduct of flight. Particularly important to aviation are conditions such as spatial disorientation, visual illusions, hypoxia, illness, intoxication, and a whole host of pharmacological and medical abnormalities known to affect performance.

Physical and/or mental limitations of the operator, the third and final category of substandard condition, includes those instances when necessary sensory information is either unavailable, or if available, individuals simply do not have the aptitude, skill, or time to safely deal with it.

Substandard Practices of the Operator

Often times, the substandard practices of aircrew will lead to the conditions and unsafe acts described above. For instance, the failure to ensure that all members of the crew are acting in a coordinated

manner can lead to confusion (adverse mental state) and poor decisions in the cockpit. Crew resource mismanagement, as it is referred to here, includes the failures of both inter- and intra-cockpit communication, as well as communication with ATC and other ground personnel.

Equally important however, individuals must ensure that they are adequately prepared individually for flight. Consequently, the category of personal readiness was created to account for those instances when rules such as disregarding crew rest requirements, violating alcohol restrictions, self-medicating, are not adhered to. However, even behaviors that do not necessarily violate existing rules or regulations (e.g., running 10 miles before piloting an aircraft or poor dietary practices) may reduce the operating capabilities of the individual and are therefore captured here.

METHODS

The focus of this study was on GA CFIT accidents – in particular, those fixed-wing aircraft operating under Federal Air Regulations Part 91. Excluded from this study were ultra-light aircraft, helicopters, and aircraft used for commercial or agricultural purposes. With these parameters, the original 195 CFIT accidents identified by Volpe (1997) and used by the CFIT JSAT was reduced to 164 accidents.

Using accident data maintained by the NTSB and FAA a variety of demographic and descriptive data (e.g., time of day, weather, lighting, etc.) associated with the 164 CFIT accidents were extracted. In addition, a panel of experts using the HFACS causal categories classified each human causal factor identified by the NTSB. The panel consisted of three subject matter experts (two psychologists and one GA pilot) who independently coded each accident using the HFACS framework. Where differences existed, consensus was reached and the agreed upon code entered into the database. Only those causes and factors identified by the NTSB were analyzed. That is, no new causal factors were identified nor were the accidents reinvestigated.

RESULTS

All the human causal factors described by the NTSB were coded using the HFACS framework. Not surprising however, given the nature of general

aviation, the majority of causal factors were coded within the bottom two tiers of the HFACS framework (Unsafe acts; Preconditions for Unsafe Acts). In fact, an inspection of Table 1 revealed that the CFIT accidents examined here were most frequently associated with skill-based and decision errors, as well as violations of the rules.

Using descriptive data provided by the FAA and NTSB, it was possible to examine relationships of specific error types and violations with pilot mortality, weather conditions and type of terrain. For instance, a larger proportion of CFIT accidents that involved violations were fatal (84%) than those that did not involve a violation (16%). Likewise, a larger proportion of CFIT accidents involving violations were associated with flight into instrument meteorological conditions (IMC) (92%; $\phi=.509$, $p<.001$). In contrast, a larger percentage of accidents that involved skill-based errors occurred in VMC (56%;) than those that did not involve skill-based errors (46%; $\phi=.227$, $p<.05$). Surprisingly, CFIT accidents involving perceptual errors were also more prevalent in VMC (75 %; $\phi=.267$, $p<.01$). Finally, perceptual errors were more often seen in flat terrain (75%) than in mountainous terrain (25%; $\phi=.290$, $p<.001$).

Table 1. Number and percentage of accidents associated with each HFACS causal category.

	Frequency	Percentage ¹
Unsafe Acts		
Skill-based Errors	80	48.8
Decision Errors	73	44.5
Perceptual Errors	28	17.1
Violations	50	30.5
Precondition for Unsafe Acts		
Adverse Mental States	12	7.3
Adverse Physiological States	9	5.5
Physical/Mental Limitations	21	12.8
Crew Resource Mismanagement	23	14
Personal Readiness	0	0

¹Note that the percentages will not add up to 100% since accidents are typically associated with multiple causal factors.

CONCLUSIONS

When considering CFIT accidents, one obvious question comes to mind - "why do pilots fly perfectly good aircraft into the ground?" (Shappell & Wiegmann, 1995; 1997b). Historically, several explanations for CFIT have been offered such as the loss of visual cues at night or during IMC, inattention

or distraction during periods of high workload, or simply poor aviation skills. In response, civilian and military organizations have instituted more conservative altitude restrictions, provided additional safety awareness, and employed the use of altitude and ground proximity warning systems (GPWS).

Undoubtedly, these intervention strategies have helped save many lives by either requiring aircrews to maintain greater separation from hazardous terrain or by alerting flight crews to an impending collision with the terrain. However, their utility in the realm of general aviation varies dramatically from that of the military or their commercial aviation counterparts. First, and foremost, the general aviation enthusiasts do not typically have the deep pockets of the military or commercial sector making many new technologies such as GPWS difficult to afford. Furthermore, the enforcement of existing Federal Air Regulations is not as effective in GA as there are more GA aircraft in the U.S. than there are military and commercial aircraft combined. Not to mention that many of these GA aircraft fly in unrestricted airspace. These two facts alone make the use of GPWSs or more conservative altitude restrictions unlikely to have an effect on GA CFIT.

So what can be done to reduce GA CFIT accidents? As a first step, the FAA commissioned a GA CFIT JSAT to examine the issue in detail. Using root cause analysis on 195 GA CFIT accidents, the CFIT JSAT identified 55 intervention strategies the top 10 of which are presented in Table 2.

Table 2. CFIT JSAT top 10 recommended intervention strategies (in no particular order).

1. Increase pilot awareness on accident causes.
2. Improve safety culture within the aviation community.
3. Promote development and use of low cost terrain clearance and/or look ahead device.
4. Improve pilot training (i.e., weather briefing, equipment, decision-making, wire and tower avoidance, and human factors).
5. Improve the quality and substance of weather briefs.
6. Enhance the Biennial Flight Review and/or instrument competency check.
7. Develop and distribute mountain flying technique advisory material.
8. Standardize and expand use of markings for towers and wires.
9. Use high visibility paint and other visibility enhancing features on obstructions.
10. Eliminate the pressure to complete the flight where continuing may compromise safety.

Source: General Aviation Controlled Flight into Terrain Joint Safety Implementation Team (JSIT) Final Report, January 4, 2000.

While thorough and introspective, the CFIT JSAT might have benefited from a more traditional human error approach. In fact, using the HFACS framework presented above, many of the recommended intervention strategies developed by the CFIT JSAT map directly onto the findings presented here. For instance, the HFACS analysis suggests that skill-based (49%) and decision errors (45%) are the leading human causal factors associated with the CFIT accidents examined. With that in mind, efforts aimed at improving pilot training and awareness of those causal factors inherent in CFIT would likely reduce the number of CFIT accidents due to skill-based and decision errors, respectively. Likewise, enhancing the biennial flight review (BFR) should affect those accidents due to skill-based errors if for no other reason than to reinforce such basic flight skills as instrument scan and situation awareness.

While at least three of the top 10 interventions developed by the CFIT JSAT address skill-based and decision errors, none appear to directly affect the large percentage of CFIT accidents due to violations of existing rules and regulations (31%). In fact, a closer examination of the data here suggests that the majority of violations occurred in IMC and tragically, were more often fatal than when other unsafe acts were committed. Indirectly then, several recommendations of the CFIT JSAT appear to address the conditions inherent in many of these violations. For example, improving the quality and substance of weather briefs may affect pilot decision-making when planning a flight. That is, pilots may choose not to proceed given better weather briefs, and therefore would theoretically not find themselves in IMC when they were either not qualified to fly in those conditions or unprepared. However, equally important among violations are such attitudes as overconfidence and the pressure to proceed to the next destination. Certainly, interventions such as eliminating the pressure to complete the flight in the interest of safety, and improving the overall safety culture (both recommended by the CFIT JSAT) will address this need.

However, it cannot be ignored that enforcing the regulations will also have a dramatic effect on violations. Just as strict enforcement of posted speed limits on military and government facilities ensure that laws are adhered to, so to will the enforcement of federal regulations regarding continuing into IMC without adequate training or authorization. While enforcement is a difficult proposition for many

reasons, it should nevertheless be considered among the other intervention strategies.

What was surprising here was the limited percentage of CFIT accidents associated with perceptual errors and adverse physiological states. Traditionally, CFIT has been attributed to spatial disorientation and visual illusions that occur during visually impoverished environments such as those experienced during IMC or at night. Nevertheless, only 17% of the CFIT accidents examined occurred as the result of perceptual errors (17%) and even fewer due to spatial disorientation (6%). In fact, nearly half of the accidents occurred in VMC or during daylight conditions. It is unclear then, to what extent using technology such as a GPWS or other terrain avoidance technology would help. What may help however, is the use of high visibility paint and other enhancing features on obstructions combined with improved visual scan and safety awareness (all recommended in some form by the CFIT JSAT). Nevertheless, the development of a low cost terrain clearance or “look ahead” device may be worth examining.

Finally, the CFIT JSAT recommended the development of mountain flying technique advisory materials. While on the surface this makes sense (i.e., the perception that pilots are simply flying into mountains), not all CFIT occur in mountainous terrain. In fact, nearly half of the CFIT accidents examined here occurred on flat terrain and more often were associated with perceptual errors. Indeed, a GPWS may have proven useful in those instances.

Regardless of how one examines the data, using root cause analysis or a human error framework like HFACS, no single intervention will eliminate GA CFIT accidents. What is needed is a strategy that combines several interventions into a concerted effort. More important, a means to track intervention strategies is required to assess the viability of each recommended intervention on specific error forms – a proven quality of the HFACS framework. In fact, work is currently underway at the Civil Aeromedical Institute that will examine all GA CFIT accidents occurring between 1990 and 1998 (not just 1993 and 1994 as was done here) to identify underlying trends in the data. Efforts to track interventions will continue in the years to follow.

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